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backscatter radiation can be manipulated to indicate the sensor result by modulating the antenna impedance.

[0074] FIG. 4B is a flowchart of a process 420 for operating an external reader to interrogate an amperometric sensor in an eye-mountable device to measure a tear film analyte concentration. Radio frequency radiation is transmitted to an electrochemical sensor mounted in an eye from the external reader (422). The transmitted radiation is sufficient to power the electrochemical sensor with energy from the radiation for long enough to perform a measurement and communicate the results (422). For example, the radio frequency radiation used to power the electrochemical sensor can be similar to the radiation 341 transmitted from the external reader 340 to the eye-mountable device 310 described in connection with FIG. 3 above. The external reader then receives backscatter radiation indicating the measurement by the electrochemical analyte sensor (424). For example, the backscatter radiation can be similar to the backscatter signals 343 sent from the eye-mountable device 310 to the external reader 340 described in connection with FIG. 3 above. The backscatter radiation received at the external reader is then associated with a tear film analyte concentration (426). In some cases, the analyte concentration values can be stored in the external reader memory (e.g., in the processing system 346) and/or a network-connected data storage.

[0075] For example, the sensor result (e.g., the measured amperometric current) can be encoded in the backscatter radiation by modulating the impedance of the backscattering antenna. The external reader can detect the antenna impedance and/or change in antenna impedance based on a frequency, amplitude, and/or phase shift in the backscatter radiation. The sensor result can then be extracted by associating the impedance value with the sensor result by reversing the encoding routine employed within the eye-mountable device. Thus, the reader can map a detected antenna impedance value to an amperometric current value. The amperometric current value is approximately proportional to the tear film analyte concentration with a sensitivity (e.g., scaling factor) relating the amperometric current and the associated tear film analyte concentration. The sensitivity value can be determined in part according to empirically derived calibration factors, for example.

IV. Analyte Transmission to the Electrochemical Sensor

[0076] FIG. 5A shows an example configuration in which an electrochemical sensor detects an analyte from the inner tear film layer 40 that diffuses through the polymeric material 220. The electrochemical sensor can be similar to the electrochemical sensor 320 discussed in connection with FIG. 3 and includes a working electrode 520 and a reference electrode 522. The working electrode 520 and the reference electrode 522 are each mounted on an inward-facing side of the substrate 230. The substrate 230 is embedded in the polymeric material 220 of the eye-mountable device 210 such that the electrodes 520, 522 of the electrochemical sensor are entirely covered by an overlapping portion 512 of the polymeric material 220. The electrodes 520, 522 in the electrochemical sensor are thus separated from the inner tear film layer 40 by the thickness of the overlapping portion 512. The thickness of the overlapping region 512 can be approximately 10 micrometers, for example.

[0077] An analyte in the tear film diffuses through the overlapping portion 512 to the working electrode 520. The diffusion of the analyte from the inner tear film layer 40 to the working electrode 520 is illustrated by the directional arrow 510. The current measured through the working electrode 520 is based on the electrochemical reaction rate at the working electrode 520, which in turn is based on the amount of analyte diffusing to the working electrode 520. The amount of analyte diffusing to the working electrode 520 can in turn be influenced both by the concentration of analyte in the inner tear film layer 40, the permeability of the polymeric material 220 to the analyte, and the thickness of the overlapping region 512 (i.e., the thickness of polymeric material the analyte diffuses through to reach the working electrode 520 from the inner tear film layer 40). In the steady state approximation, the analyte is resupplied to the inner tear film layer 40 by surrounding regions of the tear film 40 at the same rate that the analyte is consumed at the working electrode 520. Because the rate at which the analyte is resupplied to the probed region of the inner tear film layer 40 is approximately proportionate to the tear film concentration of the analyte, the current (i.e., the electrochemical reaction rate) is an indication of the concentration of the analyte in the inner tear film layer 40.

[0078] Where the polymeric material is relatively impermeable to the analyte of interest, less analyte reaches the electrodes 520, 522 from the inner tear film layer 40 and the measured amperometric current is therefore systematically lower, and vice versa. The systematic effects on the measured amperometric currents can be accounted for by a scaling factor in relating measured amperometric currents to tear film concentrations. Although after the eye-mountable device is in place over the eye for a period of time, the analyte concentration itself can be influenced by the permeability of the polymeric material 220 if the analyte is one which is supplied to the tear film by the atmosphere, such as molecular oxygen. For example, if the polymeric material 220 is completely impermeable to molecular oxygen, the molecular oxygen concentration of the inner tear film layer 40 can gradually decrease over time while the eye is covered, such as by an exponential decay with a half life given approximately by the time for half of the oxygen molecules in the inner tear film layer 40 to diffuse into the corneal tissue. On the other hand, where the polymeric material 220 is completely oxygen permeable, the molecular oxygen concentration of the inner tear film layer 40 can be largely unaffected over time, because molecular oxygen that diffuses into the corneal tissue is replaced by molecular oxygen that permeates through the polymeric material 220 from the atmosphere.

[0079] FIG. 5B shows an example configuration in which an electrochemical sensor detects an analyte from the tear film that contacts the sensor via a channel 530 in the polymeric material 220. The channel 530 has side walls 532 that connect the concave surface 226 of the polymeric material 220 to the substrate 230 and/or electrodes 520, 522. The channel 530 can be formed by pressure molding or casting the polymeric material 220 for example. The height of the channel 530 (e.g., the length of the sidewalls 532) corresponds to the separation between the inward-facing surface of the substrate 230 and the concave surface 226. That is, where the substrate 230 is positioned about 10 micrometers from the concave surface 226, the channel 530 is approximately 10 micrometers in height. The channel 530 fluidly connects the inner tear film layer 40 to the sensor electrodes 520, 522. Thus, the working electrode 520 is in direct contact with the inner tear film layer 40. As a result, analyte transmission to the working electrode 520 is unaffected by the permeability of the polymeric material 220 to the analyte of interest. The